MEMORANDUM

DATE: July 28, 2011

SUBJECT: Composition of Natural Gas for use in the Oil and Natural Gas Sector Rulemaking

FROM: Heather P. Brown, P.E.

TO: Bruce Moore, EPA/OAQPS/SPPD

The purpose of this memorandum is to document the development of a representative natural gas composition for use in the oil and natural gas sector rulemaking. This composition will be used to determine hazardous air pollutant (HAP) and volatile organic compound (VOC) emissions from several segments of the oil and natural gas sector.

Gas composition data was compiled from several sources across the industry. The following is a list of the sources of data used for this analysis:

- CENRAP database. "Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventory", November 13, 2008. Covers the following States: Texas, Louisiana, Arkansas, Oklahoma, Kansas, Nebraska, Missouri, Iowa, and Minnesota
- GTI Database. "GTI's Gas Resource Database, Second Edition – August 2001"
- TX Barnett Shale. "Emissions from Natural Gas Production in the Barnett Shale Area and Opportunities for Cost-Effective Improvements", January 26, 2009
- INGAA/API Compendium. "Greenhouse Gas Emission Estimation Guidelines for Natural Gas Transmission and Storage Volume 1 – GHG Emission Estimation Methodologies and Procedures" September 28, 2005
- GOADS Offshore. "Year 2005 Gulfwide Emission Inventory Study" December 2007
- NREL LCA. "Life Cycle Assessment of a Natural Gas Combined-Cycle Power Generation System" September 2000
- Union Gas. Chemical Composition of Natural Gas found online at http://www.uniongas.com/aboutus/aboutng/composition.asp
- Marcellus. "Supplemental Generic Environmental Impact Statement On The Oil, Gas and Solution Mining Regulatory Program - Well Permit Issuance for Horizontal Drilling And High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs" September 2009
- Wyoming DEQ. Speciation of Natural Gas and Condensate. Courtesy of Cynthia Madison, Wyoming DEQ

Tables 1 and 2 present a summary of the methane, VOC, and HAP contents provided in the above data sources for the production and transmission sectors, respectively, along with an identification of the basins/areas of the country covered by the gas composition.

In addition to the above, gas composition data were collected from the industry in 1995 during the development of the original maximum achievable control technology (MACT) standards for this sector. These data are presented in Tables 3 and 4 for production and transmission, respectively.[1] This 1995 GRI data represents gas samples from across the United States.

Gas Composition for Pneumatics, Equipment Leaks, and Compressors

Tables 1 and 2 also present a comparison of the 1995 GRI data to the other data sources. For production, the 1995 GRI data is well within the ranges of the other data sources which range from 1.19 to 11.6 percent for VOC by volume. The 1995 GRI data is also within the 95 percent confidence interval of the production data which range from 2.81 to 7.82 percent volume for VOC. Of the data sources that provide data on HAP emissions, the GRI data represent gas compositions across the United States, while the CENRAP, TX Barnett, and Marcellus data are specific to the regions specified in Tables 1 and 2. In addition, it can be expected that the gas composition for pneumatic controllers, equipment leaks, and compressors associated with these emissions units are associated with gas from oil wells and gas wells making the range of VOC composition widely varied. Therefore, it was determined that the 1995 GRI data was appropriate to use to develop a representative gas composition for pneumatic controllers, equipment leaks, and compressors.

For the transmission sector, the average 1995 GRI VOC concentration of 0.89 percent volume was compared to other data sources and was found to be in the range of the VOC composition, which ranged from 0.29 to 6.84 percent VOC by volume. It was determined that the 1995 GRI gas composition would be used to represent the average composition of natural gas in the transmission sector, because the other data sources represented natural gas compositions outside the U.S.[i]

The gas compositions from the 1995 GRI data were then converted to weight percents. First, because the average volume percent was not equal to 100, the volume percents were normalized for each component. Then the weight of each component present in the gas was calculated using the molecular weight (MW) for each component in pounds per pound mole (lb/lbmol) and an assumed gas volume of 385 cubic feet (ft^3), which represents one pound mole of gas. Finally, relative weight percents for each component were calculated. These weight percents are presented in Table 5.

[i] It should be noted that the GRI data contains a statement that the BTEX data are "skewed toward high BTEX and VOC content gases…." However, the 1995 GRI data are within the ranges of the other data and very close to the average of other data identified. Therefore, these data were determined to be appropriate to use to develop a representative gas composition for pneumatics, equipment leaks and compressors.

Table 1. Gas Composition (volume %) for Production Sector

Data Source[a]	Source of Natural Gas	Area Covered	Volume %		
			Methane	VOC	HAP
CENRAP[b]	Conventional Gas Wells	11 Basins: Louisiana Mississippi Salt, Southern Oklahoma, Nemaha Uplift, Arkoma, Cambridge Arch Central Kansas Uplift, Fort Worth, Cherokee Platform, Permian, East TExas, Western Gulf, and Anadarko	87.8	3.50	0.019
GTI Database[c]	Gas Wells	Nationwide, proven reserves, and undiscovered reserves data from 462 basins/formations	82.8	3.61	n/a
INGAA	Unprocessed Natural Gas	Unknown	80.0	5.00	n/a
NREL LCA[d]	Gas Well	Worldwide	65.7	5.66	n/a
MARCELLUS[e]	Gas Well	Marcellus	97.2	2.02	0.03345
WYOMING DEQ[b]	Gas Well	Wyoming	92.4	1.19	0.08
		Minimum	**65.7**	**1.2**	**0.0**
		Maximum	**97.2**	**5.7**	**0.1**
		Average	**84.3**	**3.50**	**0.0**
Gas Composition	Production	Nationwide	83.1	3.66	0.164

n/a = not available

[a] Data from the Barnett Shale database was not speciated and therefore not included in this analysis.

[b] HAP data contains BTEX and n-Hexane

[c] HAP Speciation not provided; hexanes reported as Hexanes Plus

[d] Data provided were ranges for each pollutant (min and max). These values represent normalized averages of these values and may not be valid representations

[e] HAP data only reported for hexane

Table 2. Gas Composition (volume %) for Transmission Sector

Data Source	Source of Natural Gas	Area Covered	Volume %		
			Methane	VOC	HAP
INGAA	Pipeline Gas	Unknown	91.9	6.84	n/a
GOADS Offshore[a]	Sales Gas	Offshore Gas in the Gulf of Mexico	94.5	1.27	0.099
NREL LCA	Pipeline Gas	Worldwide	94.4	0.90	n/a
Union Gas	Pipeline Gas	United States, Western Canada, and Ontario	95.2	0.29	n/a
Minimum			**91.9**	**0.3**	**0.099**
Maximum			**95.2**	**6.8**	**0.099**
Average			**94.0**	**2.3**	**0.099**
GRI-MACT	Transmission/Unknown	Nationwide	92.7	0.89	0.014

n/a = not available

[a] HAP data contains BTEX and n-Hexane

Table 3. 1995 MACT Correspondence with GRI & EC/R- Production Data

Sector	Production											
Site	GRI1	GRI2	GRI3	GRI4	GRI5	GRI6	GRI7	GRI8	GRI9	GRI10	GRI11	GRI12
Mole %												
Nitrogen	2.72	0.44	0.78	0.46	0.79	1.52	1.18	1.74	1.90	1.30	0.52	6.81
Carbon Dioxide	0.04	0.90	0.29	3.37	1.00	0.38	1.67	0.68	0.00	0.47	0.54	8.12
Methane	95.60	93.26	90.62	56.62	80.40	78.38	79.55	74.67	83.90	91.93	88.40	79.83
Ethane	1.04	3.16	4.31	10.87	10.41	10.88	10.40	12.57	7.90	3.80	7.25	2.89
Propane	0.33	1.14	1.90	13.90	4.25	5.41	4.15	5.98	3.86	1.23	1.53	0.94
Butanes	0.16	0.64	1.15	8.59	1.65	2.10	1.74	2.55	1.70	0.70	0.90	0.54
Pentanes	0.07	0.22	0.51	3.61	0.65	0.77	0.69	1.21	0.49	0.24	0.36	0.30
Hexanes+	0.03	0.20	0.37	2.03	0.60	0.36	0.43	0.35	0.17	0.24	0.42	0.52
ppmv												
n-Hexane	88.7	277	664	2783	965	1173	937	2125	517	307	510	681
Isooctane	8.0	31.5	63.5	1552	151	145	112	103	52.0	49.6	32.0	87.0
Benzene	4.9	257	218	328	294	74.4	294	102	57.9	143	617	196
Toluene	2.9	108	117	251	468	92.4	263	31.4	45.6	142	222	213
Ethylbenzene	0	19.7	6.7	27.3	14.5	4.3	3.3	0.8	1.2	11.2	9.0	10.4
m,p-Xylenes	0	34.0	26.6	26.0	87.9	21.7	16.7	1.7	7.3	56.6	45.0	66.0
o-Xylene	0	19.9	5.0	6.2	16.1	3.2	2.4	0.3	0.6	16.9	10.0	16.4

NR = Not Reported

Table 4. 1995 MACT Correspondence with GRI & EC/R (Transmission Data)

Sector	Transmission		Unknown[a]		Transmission	Unknown[a]	Transmission					
Site	GRI13	GRI14	GRI15	GRI16	GRI17	GRI18	GRI19	GRI20	GRI21	GRI22	GRI23	GRI24
Mole %												
Nitrogen	9.89	8.68	2.96	2.55	0.22	1.25	1.16	1.1	1.15	1.12	0.3	1.85
Carbon Dioxide	0.28	0.40	0.58	0.54	0.35	2.62	0.15	0.12	0.07	1.06	1.36	0.66
Methane	81.97	82.61	91.8	92.7	97.4	95.4	98.5	88.2	81.1	94.6	95.8	93
Ethane	6.84	7.06	3.68	3.35	1.94	0.31	0.09	9.69	11.8	2.81	2.03	3.13
Propane	0.78	0.99	0.59	0.52	0.042	0.075	0.005	0.67	3.95	0.155	0.4	0.8
Butanes	0.14	0.17	0.159	0.148	<0.006	0.059	<0.006	0.035	1.189	0.116	0.075	0.314
Pentanes	0.04	0.05	0.045	0.042	<0.003	0.039	<0.003	<0.003	0.341	0.039	0.014	0.132
Hexanes+	0.04	0.03	0.042	0.042	0.004	0.202	<0.002	<0.002	0.226	0.129	0.015	0.103
ppmv												
n-Hexane	63.2	66.9	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Isooctane	17.5	14.5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Benzene	5.0	7.9	51	36	<0.2	471	<0.2	<0.2	10	<0.2	4.5	15
Toluene	5.1	8.1	16	13	<0.1	100	<0.1	<0.1	13	<0.1	3.7	14
Ethylbenzene	0.5	0.6	3	3	<0.1	15	<0.1	<0.1	9	<0.1	0.1	1
m,p-Xylenes [1]	1.4	2.2	12	7	<0.1	11	<0.1	<0.1	1	<0.1	0.6	3
o-Xylene [1]	0.4	0.4										

[1] Sites 15-36 reported only a total xylene result that includes all xylene isomers.

NR = Not Reported

[a] Based on the high methane content (greater than 90 percent) of this datapoint, it was assumed that they were samples from the transmission segment.

Table 4. 1995 MACT Correspondence with GRI & EC/R - Transmission Data (Continued)

Sector	Transmission					Unknown [a]	
Site	GRI25	GRI26	GRI27	GRI28	GRI29	GRI30	GRI31
Mole %							
Nitrogen	1.24	1.75	1.02	1.04	0.49	0.42	0.54
Carbon Dioxide	0.3	0.13	0.44	0.65	1.76	0.87	0.92
Methane	90.2	97.8	96.6	96.1	95.5	96	95.7
Ethane	7.02	0.26	1.78	1.86	1.74	2	2.12
Propane	1	0.014	0.091	0.213	0.351	0.413	0.414
Butanes	0.146	<0.006	0.025	0.06	0.093	0.181	0.175
Pentanes	0.03	0.0015	0.0089	0.0218	0.0354	0.0675	0.0665
Hexanes+	0.021	0.0037	0.0052	0.0219	0.0322	0.073	0.069
ppmv							
n-Hexane	NR	NR	NR	NR	NR	NR	NR
Isooctane	NR	NR	NR	NR	NR	NR	NR
Benzene	9	1.2	0.8	6	7	59	58
Toluene	13	0.4	<0.4	6	6	23	26
Ethylbenzene	<0.3	0.3	<0.1	0.3	0.5	1.8	2
m,p-Xylenes [1]	4	0.2	<0.1	1	1.5	7	5
o-Xylene [1]							

[1] Sites 15-36 reported only a total xylene result that includes all xylene isomers.
NR = Not Reported
[a] Based on the high methane content (greater than 90 percent) of this datapoint, it was assumed that they were samples from the transmission segment.

Table 5. Gas Composition Conversion to Weight Percent

Component	MW (lb/lbmol)	Production				Transmission			
		Avg Vol %[b]	Normalized Vol %	Weight per 385 ft^3 Gas (lbs)	Weight %	Avg Vol %[b]	Normalized Vol %	Weight per 385 ft^3 Gas (lbs)	Weight %
Carbon Dioxide	44.01	1.46	1.5%	0.002	3.2%	0.70	0.70%	0.001	1.8%
Nitrogen	28.02	1.68	1.7%	0.001	2.3%	2.04	2.0%	0.001	3.3%
Methane	16.04	82.76	82.9%	0.035	65.7%	92.68	92.8%	0.039	86.2%
Ethane	30.07	7.12	7.1%	0.006	10.6%	3.66	3.7%	0.003	6.4%
Propane	44.09	3.72	3.7%	0.004	8.1%	0.60	0.60%	0.001	1.5%
Butane	58.12	1.87	1.9%	0.003	5.4%	0.16	0.16%	0.000	0.55%
Pentane	72.15	0.76	0.76%	0.001	2.7%	0.05	0.052%	0.000	0.22%
n-Hexane	86.17	0.09	0.092%	0.000	0.39%	0.01	0.0065%	0.000	0.032%
Other hexanes	86.17	0.32	0.32%	0.001	1.4%	0.001	0.00086%	0.000	0.0043%
Isooctane-a	114.23	0.02	0.020%	0.000	0.11%	0.002	0.0016%	0.000	0.011%
Benzene	78.11	0.02	0.022%	0.000	0.083%	0.004	0.0039%	0.000	0.018%
Toluene	92.14	0.02	0.016%	0.000	0.074%	0.001	0.0013%	0.000	0.0070%
Ethylbenzene	106.17	0.001	0.00090%	0.000	0.0047%	0.0002	0.00020%	0.000	0.0012%
Xylene	106.17	0.004	0.0041%	0.000	0.021%	0.0003	0.00030%	0.000	0.0019%
Total		99.85	100.0%	0.053	100.0%	99.91	100.0%	0.045	100.0%

a- Isooctane = 2,2,4, Trimethylpentane

b- Average of all gas compositions presented in Tables 1 and 2 for production and transmission, respectively.

Once the weight percents were calculated for each natural gas component, relative ratios were calculated for methane:total organic compounds (TOC), VOC:TOC, HAP:TOC, VOC:Methane, HAP:Methane, BTEX:Methane, HAP:VOC, and BTEX:VOC. These relative ratios are presented in Table 6.

Natural Gas Composition for Completions and Recompletions

The gas composition for completions and recompletions from gas wells were determined by performing a sensitivity analysis on the compositions of the gas well data using a larger sample size which included data from hydraulically fractured wells. The results of this analysis are shown in Table 7. A mean of 3.63 percent VOC with a 95 percent confidence interval that ranges from 3.30 to 3.96 percent VOC by volume was determined. Based on the summary statistics, these data appear to be reasonable for use in developing an average natural gas composition to use for completions and recompletions of gas wells.

Once it was determined that this data was appropriate, the average gas composition was calculated and then normalized so that the total volume percent equaled 100. This average gas composition is presented in Table 8. The gas composition data was then converted to weight percent by normalizing the volume percent for each component, then calculating the weight of each component using the MW for each component in lb/lbmol and a standard gas volume of 385 ft^3. Finally, relative weight percents for each component were calculated. Once the weight percents were calculated for each natural gas component, relative ratios were calculated for methane:total organic compounds (TOC), VOC:TOC, HAP:TOC, VOC:Methane, HAP:Methane, BTEX:Methane, HAP:VOC, and BTEX:VOC. These relative ratios are presented in Table 9.

A similar analysis was performed for completions and recompletions from oil wells. The results of this analysis are presented in Table 10. The average VOC composition was 11.62 percent by volume, with a 95 percent confidence interval that ranges from 6.73 to 16.5 percent VOC by volume. As was done for gas wells, the average composition was normalized. The gas composition used for completions and recompletions for oil wells is presented in Table 8. The gas composition data was converted to weight percent using the same approach detailed for gas wells and are presented in Table 9.

Table 6. Weight Ratios to Use in Estimating Emissions

	Production	Transmission
Methane:TOC[a]	0.695	0.908
VOC[b]:TOC[a]	0.193	0.0251
HAP:TOC[a]	0.00728	0.000746
VOC[b]:Methane	0.278	0.0277
HAP:Methane	0.0105	0.000822
BTEX:Methane	0.00280	0.000322
HAP:VOC[b]	0.0377	0.0297
BTEX:VOC[b]	0.0101	0.0116

[a] TOC = all organic compounds listed in Table 3.
[b] VOC = all organic compounds listed in Table 3, except ethane and methane.

Table 7. Summary Statistics of Sensitivity Analysis on Gas Composition for Gas Well and Hydraulically Fractured Wells

Methane	
Mean	83.238
Standard Error	0.709
Median	86.581
Mode	0
Standard Deviation	15.207
Sample Variance	231.244
Kurtosis	12.943
Skewness	-3.08
Range	99.75
Minimum	0
Maximum	99.748
Sum	38289.387
Count	460
Confidence Level(95.0%)	1.393
	Volume Percent
(Lower of 95% conf interval)	81.844
Methane	83.238
(Higher of 95% conf interval)	84.631

VOC	
Mean	3.630
Standard Error	0.170
Median	3.104
Mode	0.000
Standard Deviation	3.626
Sample Variance	13.149
Kurtosis	9.258
Skewness	2.262
Range	29.560
Minimum	0.000
Maximum	29.560
Sum	1655.427
Count	456.000
Confidence Level(95.0%)	0.334
	Volume Percent
(Lower of 95% conf interval)	3.297
VOC	3.630
(Higher of 95% conf interval)	3.964

Table 8. Average Gas Composition for Completions and Recompletions of Gas and Oil Wells

	Average Volume Percent	
Pollutant	**Gas Wells**	**Oil Wells**
Carbon dioxide (CO2)	1.631	1.00162
Nitrogen (N2)	4.455	29.19
Methane (C1)	**83.081**	46.73
Ethane (C2)	4.924	10.17
Propane (C3)	2.144	6.62
i-Butane (i-C4)	0.348	1.067004
n-Butane (n-C4)	0.643	2.136346
i-Pentane (iC5)	0.095	0.550849
n-Pentane (nC5)	0.119	0.515798
Cyclopentane	0.005	0.001091
n-Hexane (n-C6)	0.155	0.005182
Hexanes (C6)	0.000	-
Cyclohexane	0.001	0.001455
Other Hexanes	0.010	0.007636
Methylcyclohexane	0.002	0.001818
C6+ Heavies	0.114	-
Heptanes (C7)	0.009	0.697080
n- Heptanes (C7)	0.000	0.001909
C8+ Heavies	0.004	0.005182
Benzene	0.005	0.006182
Toluene	0.003	0.000223
Ethylbenzene	0.000	0.000445
Xylenes	0.001	-
2,2,4-Trimethylpentane	0.000	0.000223
Helium	0.140	-
Oxygen	0.084	-
Hydrogen	0.001	0.575909
Hydrogen disulfide (H2S)	2.027	0.709092
Total	**100**	**100**
VOC	**3.66**	**11.62**

Table 9. Weight Ratios to Use in Estimating Emissions for Completion and Recompletions

	Gas Wells	Oil Wells
Methane:TOC[a]	0.796	**0.4453**
VOC[b]:TOC[a]	0.116	**0.3729**
HAP:TOC[a]	0.0084	**0.0006**
VOC[b]:Methane	0.146	**0.8374**
HAP:Methane	0.0106	**0.0001**
BTEX:Methane	0.0006	**0.0007**
HAP:VOC[b]	0.0726	**0.0016**
BTEX:VOC[b]	0.0040	**0.0009**

[a] TOC = all organic compounds listed in Table 3.
[b] VOC = all organic compounds listed in Table 3, except ethane and methane.

Table 10. Summary Statistics of Sensitivity Analysis on Gas Composition for Oil Wells

Methane	
Mean	46.73157
Standard Error	4.196101
Median	49.63115
Mode	49.63115
Standard Deviation	19.68146
Sample Variance	387.3598
Kurtosis	1.385922
Skewness	-1.15094
Range	71.93094
Minimum	0.156
Maximum	72.08694
Sum	1028.095
Count	22
Confidence Level(95.0%)	8.72627
(Lower of 95% Conf interval)	38.0053
Methane	46.73157
(Higher of 95% Conf. Interval)	55.45784

VOC	
Mean	11.61755
Standard Error	2.193276
Median	9.697621
Mode	#N/A
Standard Deviation	7.274275
Sample Variance	52.91508
Kurtosis	1.438744
Skewness	1.127773
Range	25.91599
Minimum	1.381007
Maximum	27.297
Sum	127.793
Count	11
Confidence Level(95.0%)	4.886924
(Lower of 95% Conf interval)	6.730621
VOC	11.61755
(Higher of 95% Conf. Interval)	16.50447

REFERENCES

1. Letter and Attachments from Evans, J. M., Gas Research Institute, to G. Viconovic, EC/R Incorporated. Natural Gas BTEX Content. April 19, 1005. Legacy Docket Number A-94-04, Item II-D-35.